Spring 2015 Research Project Report

EFFECT OF INJURY AND AXIAL COMPRESSION PRELOAD ON INTERVERTEBRAL DISC TORSIONAL MECHANICS

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INTRODUCTION

The intervertebral disc (IVD) forms a fibrocartilaginous joint that functions to absorb and transfer complex loads placed on the spine. It is composed of the fiber-reinforced annulus fibrosis (AF) and the gelatinous nucleus pulposus (NP). The annulus fibrosis is built of a matrix of collagen fibers that are aligned about ±30° to the horizontal plane, allowing it to support and distribute large multidirectional stresses and strains [1]. The AF also works to constrain and distribute fluid pressure across the NP, which functions to absorb shock and stresses applied to the disc. IVD degeneration and injury is classified as mechanical damage and enzymatic degradation through accumulated trauma and larger injuries [2]. One early degenerative change is the reduction of glycosaminoclycan (GAG) content in the nucleus pulposus, which has been shown to impact the mechanical function of the disc. Axial compression testing has been widely applied to uncover properties of disc mechanical function; however the effect of axial torsion is not as well understood. Additionally, research that does exist on the effect of axial compression and disc geometry on torsional mechanics only considers healthy intact bovine discs, there is a continued lack of information about the impact of injury on the torsional mechanics of the disc. Therefore, the purpose of this study is twofold: 1) to verify the effect of axial compression preload on the torsional mechanics of the disc as reported from a study on healthy discs. 2) To compare the behavior of injured intervertebral discs to healthy discs, in order to differentiate the mechanical function of the NP from the AF.

METHODS

Bovine caudal spines were acquired from the local abattoir (n = 3 spines, ~ 18 months). The spines were dissected to remove musculature and facet joints,

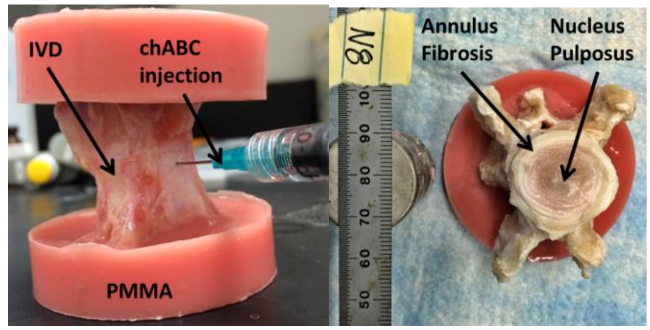

Figure 1. (A) Potted motion segment sample with enzyme injection. (B) Cut disc sample with AF and NP visible.

leaving the bone and the disc. Motion segments were cut from the spine, isolating each disc and leaving bone segments around each disc body. Segments (n = 5 samples) were potted in polymethylmetacrylate (PMMA) bone cement to ensure parallel surfaces during testing (Figure 1A). Samples were stored at -20°C prior to testing. All samples were defrosted and injected with a 200µL solution of chondroitinase ABC (chABC) and 1x phosphate-buffered saline (PBS) for an injection amount of 0.3 units enzyme per mL. Injected samples were hydrated overnight in a 1x PBS solution and allowed to equilibrate to ambient room temperature prior to mechanical testing. Motion segments were tested in an MTS uniaxial load frame, where they were mounted in a custom-built grip with screws spaced evenly 60° apart in a PBS bath. Samples were preloaded under 20N, 200N, or 500N of axial compression for 10 minutes, followed by 10 cycles of torsion (± 5°, 0.05 Hz). The three preloads were applied to each sample in a random order, to account for loading history, and samples were allowed to recover fully between experiments. Force and displacement in the y-direction was recorded, along with torque, rotation, and time during all tests.

Following mechanical testing, the disc was removed from the vertebral bodies using a scalpel and disc geometry (height and cross sectional area) was measured using a custom MATLAB (Mathworks, Inc.) algorithm (Figure 1B). The volume and polar moment of inertia (eqn. 1, [3]) were calculated for each disc sample and used to normalize mechanical properties measured from uniaxial-torque tests.

$$J = \frac{\pi(W_{AP}W_L^3 + W_{AP}^3 W_L - N_{AP}N_L^3 + N_{AP}^3 N_L)}{64} \quad (1)$$

Axial compressive stress was calculated as y-direction force divided by to total disc area. Torsional results were analyzed using the last cycle of loading. Hysteresis energy loss was defined as the area between the loading and unloading torque-rotation curve. Torsional stiffness, k_T, was defined as the slope of the torque-rotation curve at a rotation range of 0-2°. Normalized torsional stiffness [MPa/deg], T, was calculated using equation 2 and shear stress was calculated using equation 3.

$$T = k_T * \frac{h}{J} \quad (2)$$

$$\tau = T * \frac{r_{disc}}{J} \quad (3)$$

The effects of axial compressive stress on torsional disc mechanics for injured samples were compared against the same parameters for healthy discs, collected in a previous study.

RESULTS

There was a linear relationship between axial compressive preload and the average torsional stiffness for each disc, as well as between preload and average hysteresis energy (Figure 2 A, B; r = 0.99). These results validate the linear model for energy loss and torsional stiffness with compressive stress, as seen in a study with healthy discs [4].

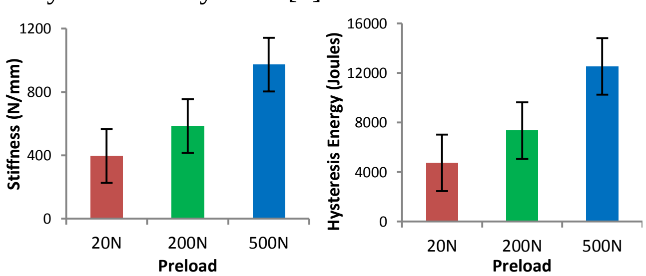

Figure 2. (A) Linear relationship between average torsional stiffness and preload. (B) Linear relationship between average energy loss and preload.

The injured IVD samples followed a different linear trend than healthy discs for torsional stiffness with respect to preload stress (Figure 3; r = 0.35). The average stiffness of the discs was higher for injured discs than healthy discs. When energy loss was normalized by disc volume, the linear trend with respect to preload stress matched the trend for healthy discs (Figure 4; r = 0.56).

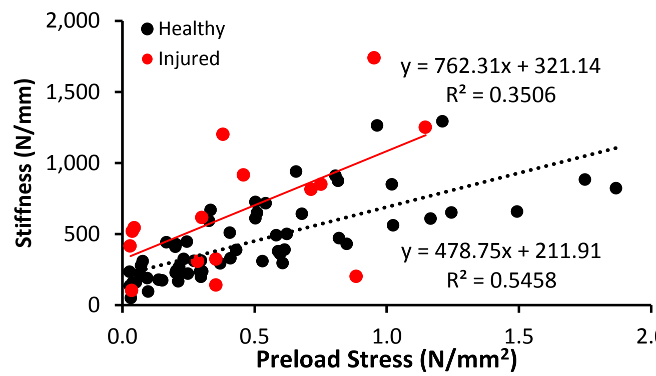

Figure 3. Comparison of normalized torsional stiffness with respect to axial compressive stress for healthy and injured discs.

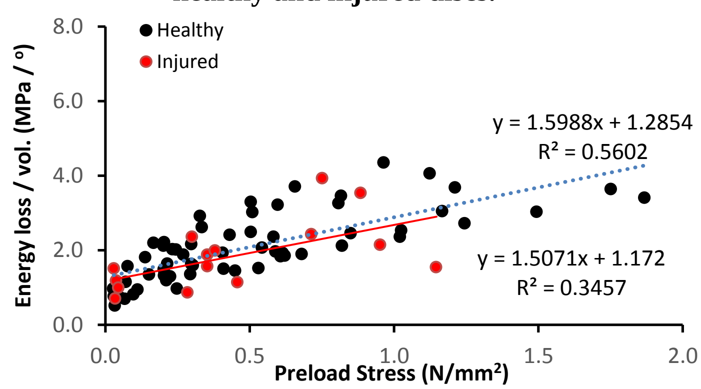

Figure 4. Comparison of normalized hysteresis energy loss with respect to axial compressive stress for healthy and injured discs.

DISCUSSION

The intervertebral disc is comprised of two very different materials, the annulus fibrosis and the nucleus pulposus. Current literature suggests that the NP plays a big role in the compressive mechanics of the disc, as it is responsible for bearing axial loads [1]. These results confirm the role of the nucleus during compressive loading, as the application of injury changed the relationship between disc stiffness and applied stress.

The results indicate that intervertebral disc stiffness is increased with injury. This is supported by the properties and mechanisms of the intervertebral disc.

ChABC injections to the disc samples reduce the GAG content in the nucleus, decreasing its ability to store water and thereby reducing its functionality [2]. However, the chABC does not affect the AF. The annulus is also load bearing, but literature indicates that the role of the annulus is especially important at high loads, when the nucleus has been fully compressed and the fibers of the annulus are required to bear stress on the disc [1]. The fibrous AF has a much higher stiffness than the nucleus, which is why the overall stiffness of injured discs is increased.

Contrastingly, these results show that there is no difference in energy loss of the disc due to injury. Again, this speaks for the role of the NP and the annulus fibrosis during loading. Hysteresis energy loss is related to torsional motion. It has been suggested that the AF plays a greater role in torsional motion than the NP, because of the alternating and angled architecture of the fibers, which gives them an advantage in bearing rotational strains. These results confirm this behavior, as the degeneration of the nucleus had no significant impact on the energy loss of the disc, showing that the nucleus does not play a great role.

However, one source of discrepancy in the data comes from heightened difference between healthy and injured samples at higher preloads than at low preloads. This is unexpected because at high preloads the nucleus is thought to become inactive and the annulus fibrosis bears the full stress. If this were true, there would not be a visible difference between healthy and injured discs at high preload stresses—the difference would occur at low preloads only. Perhaps adding more data will change the trend. If not, the experiment may need to be extended to higher preloads, to see when the nucleus becomes inactive.

CONCLUSION

The linear relationship between torsional stiffness and hysteresis energy loss with respect to compressive stress were validated with injured discs. Additionally, it was shown that injury increases the stiffness of the disc but has no impact on the energy loss of the disc during torsional loading. Current work will extend this study to include more samples. In the future, torsion-compression mechanics may be explored with different types of injury. Other studies will evaluate disc behavior of human discs to validate the response reported here.

SOURCES

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